Multilayers for present and future generations of EUVL

Yuriy Platonov, Jim Rodriguez, Michael Kriese, Vladimir Martynov

Rigaku Innovative Technologies, 1900 Taylor Rd., Auburn Hills, MI 48326, USA

Outline

- Introduction
- Choice of wavelengths for next generations of EUVL
- Deposition
- Experimental reflectivity of normal incidence multilayer structures
  - λ=13.5nm
  - λ=6.Xnm
  - Shorter wavelengths
- Conclusion

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Next Generation EUVL

EUV and BEUV product roadmap spans >10 years

	0.25 NA		0.32 NA			Under study >0.40 NA	
Lens mirrors	6M	6M	6M	6M	6M	6/8M	6/8M
Wavelength	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	13.5 nm	New λ
Product	ADT	3100	3300B	3300C	3300D	3500	>3500
Introduction year	2006	2010	2012	2013	2014	2016	>2018
Resolution (hp)	32 nm	27 nm	22 nm	18 nm	16 nm	11 nm	<8 nm
Sigma	0.5	0.8	0.2-0.9	OAI	flex OAI	flex OAI	flex OAI
Overlay (SMO)	7.0 nm	4.5 nm	3.5 nm	3.0 nm	2.5 nm		
Throughput (wph)	4 wph	60 wph	125 wph	150 wph	180 wph		
Dose (mJ/cm^2)	5	10	15	15	15		
Source (W)	3	105	250	350	500		

EUV Source Workshop, Dublin, Nov 2010

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Potential Wavelengths for NG EUVL

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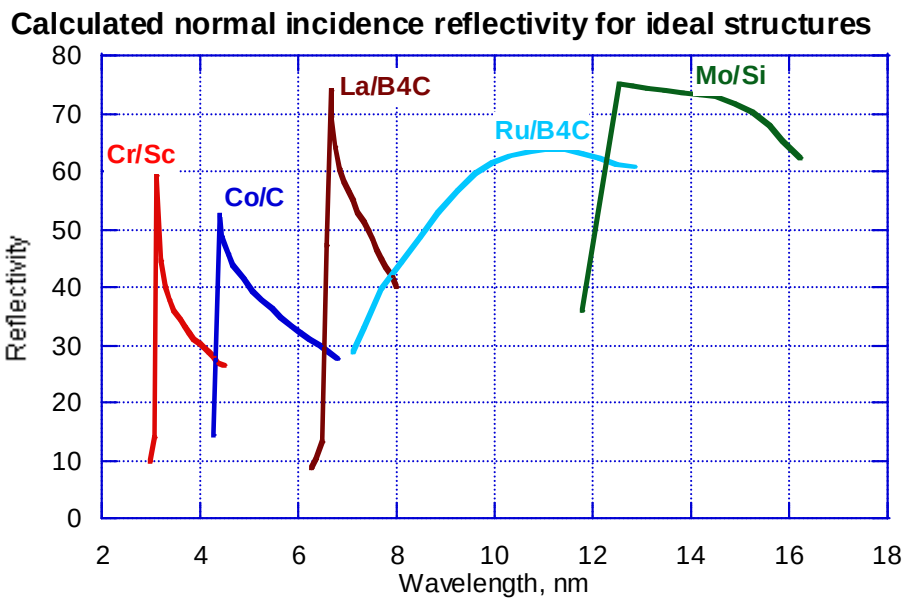
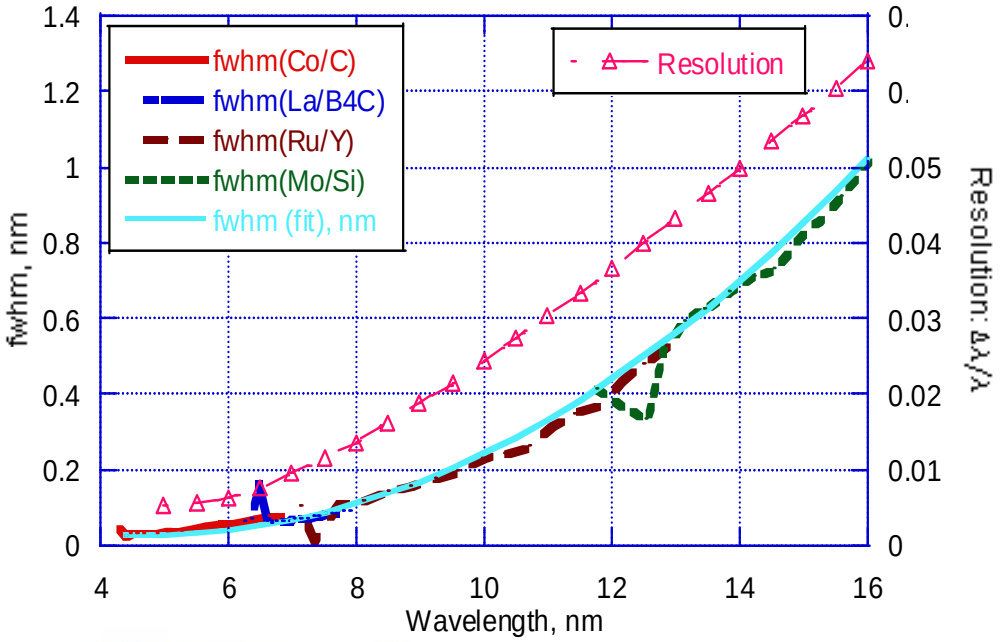
La/B_4C promises ~74% reflectivity at ~6.7nm. Next is Cr/Sc with R(max)~60% at ~3.1nm.

Reflectivity





$$\Delta\lambda = 0.20523 - 0.075113 \cdot \lambda + 0.0078905 \cdot \lambda^2$$

Shorter wavelength ⇒ **Narrower reflectivity curve**

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Flux

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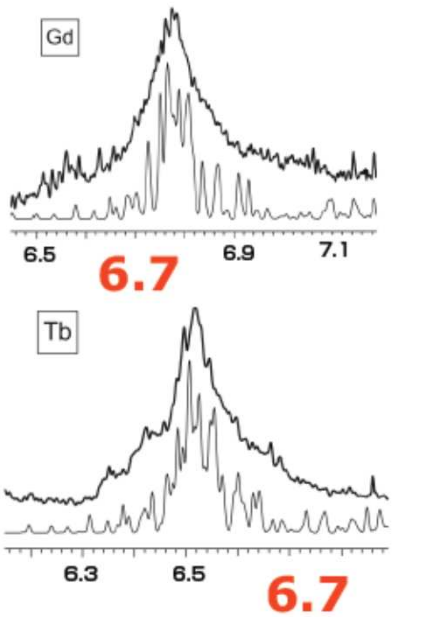
6.7 nm: Gd, Tb plasmas



S. S. Churilov *et al.*,Phys. Scr. **80**, 045303 (2009)

Optical system throughput

λ, nm	3.13	4.4	6.63	9.5	13.5
Materials pair	Cr/Sc	Co/C	La/B4C	Ru/Y	Mo/Si
R_p	0.59	0.525	0.74	0.59	0.74
Δλ, nm	0.012335	0.0240	0.0623	0.1976	0.6307
Δλ/λ (single mirror), %	0.3941	0.5444	0.9397	2.0801	4.6721
Δλ (11mirrors), nm	0.000403	0.0090	0.0226	0.0858	0.3120
Δλ/λ (11 mirrors), %	0.0129	0.2045	0.3403	0.9032	2.3111
R_p x Δλ/λ (single mirror)	2.33E-03	2.86E-03	6.95E-03	1.23E-02	3.46E-02
$R^{11}{}_p$ xΔλ/λ (11 mirrors)	6.58E-07	3.25E-06	1.68E-04	4.62E-05	1.14E-03
$R_p{}^{11}$	0.0030156	0.00083513	0.03643753	0.0030156	0.0364375

Linear spectrum

fwhm(Source) < fwhm(ML^{11})

$$Flux \sim R^{11} \frac{\Delta E_s \cdot CE(\Delta E_s)}{E}$$

→ **2nd @ 6.63nm**
3rd @ 4.4nm

Broad spectrum:

fwhm(Source) > fwhm(ML^{11})

$$Flux \sim R^{11} \frac{\Delta E_{ML} \cdot CE(\Delta E_{ML})}{E}$$

→ **2nd @ 6.63nm**
3rd @ 3.13nm

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RIT deposition facility

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- **Inline Magnetron**
- **7 Carousel Magnetrons**
- **Ion Beam**
- **Class100 cleanroom with class 10 miniroom**

- **Wavelength Range**
  λ = 0.2Å – 300Å
  E = 40eV – 60keV
- **Multilayer Period**
  d_{min} = 10Å
- **Number of Period**
  N_{max} = 1000
- **Spectral Resolution**
  $\Delta\lambda/\lambda$ = 0.2% (high-selective)
  20% (depth-graded)
- **Size**:
  ~3mm to 1.5 meter

- **Materials**
  W/Si, W/C, Ni/Ti, Ni/B_4C, Ni/C, Cr/C, Cr/Sc, Mo/Si, Mo/B_4C, La/B, V/C, Ru/B_4C, Al_2O_3/B_4C, SiC/Si, Si/C, SiC/C, Fe/Si, Cr/B_4C, Si/B_4C, W/Mg_2Si, V/B_4C, Ti/B_4C, etc.
- **Design**
  Uniform or Graded: lateral, radial, bilateral (2D)
  Depth Graded: supermirror & high-selective
  Flat or Curved
  Glancing (<1º) to Normal

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Inline Magnetron

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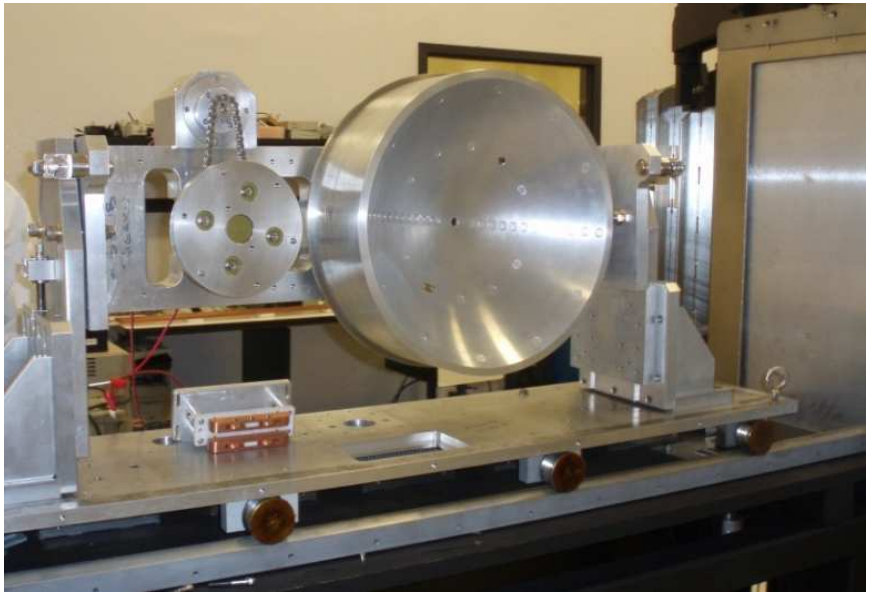

- Vacuum (load-locked)
  - 10^{-8} ultimate
  - 10^{-9} water
  - 15min from atm to 10^{-6}
- Process
  - 5 planar magnetron (RF,DC)
  - 4 process gases
  - 0.5 to 5 mTorr
  - linear ion source
  - 20-100 particles/cm^2 on optical surface

- Dual Spinning Capability

  #1: 550mm dia x 220mm thick

  #2: 175mm dia x 35mm thick
  (Compatible with velocity motion control)
- Mechanical
  - 500 x 1500mm carrier (2)
  - 0.2mm accuracy
  - 1-133 mm/sec (±0.1%)
  - velocity profiling (6 pts/mm)

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Carousel type deposition system

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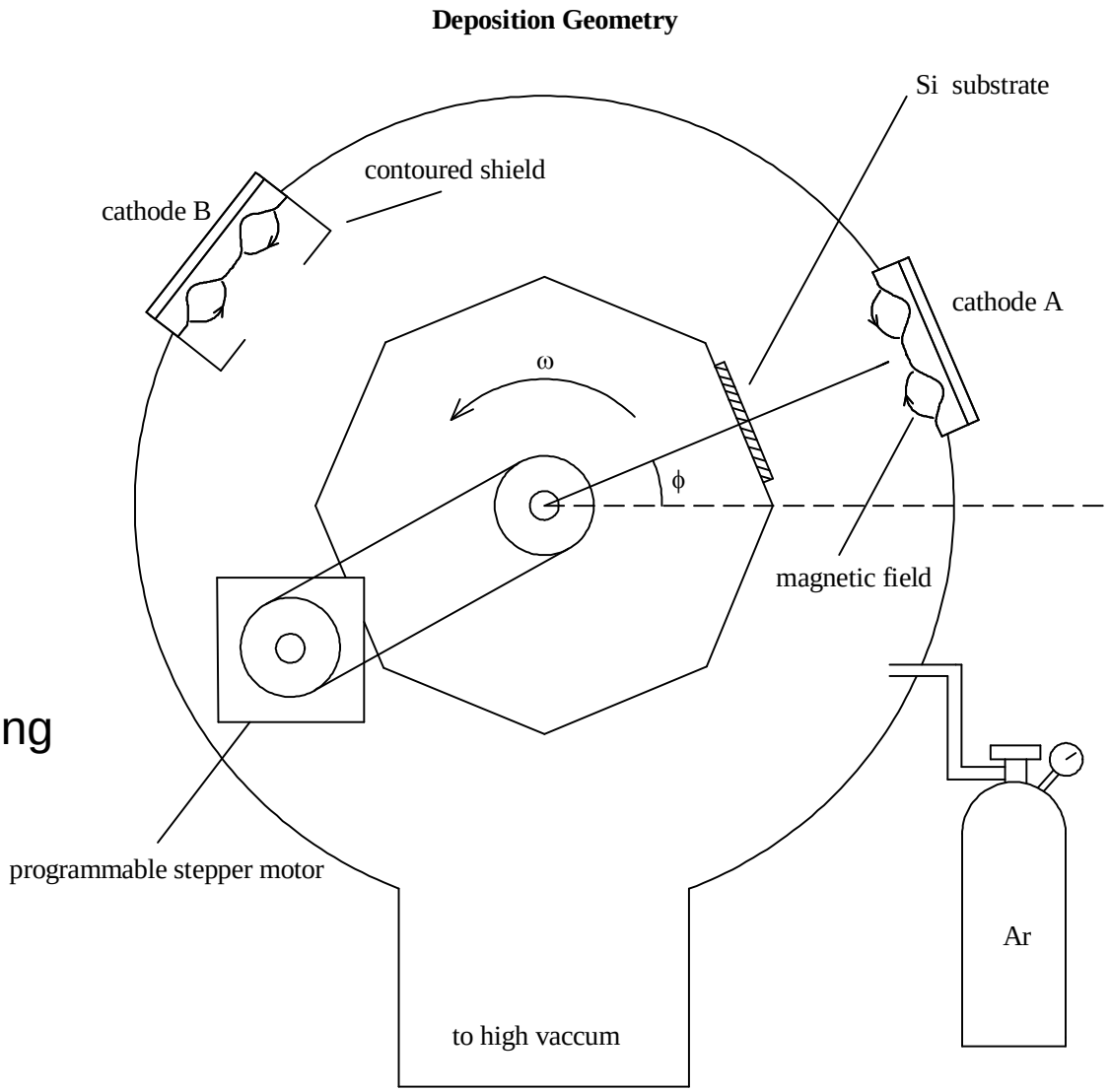
- Vacuum
  - 10^{-7} ultimate
  - 10^{-8} water
  - Typically overnight pumping
- Process
  - 3 planar magnetron (RF,DC)
    - 8”, 13”, 20”
  - 2 process gases
    - including reactive
  - 0.5 to 5 mTorr
  - linear ion source
    - for substrates pre cleaning
- Deposition area
  - 4”, 6”, 8” dia
  - 2” x 16”
- Carousel
  - 8 facets
  - Variable speed



λ=13.5nm: Reflectivity

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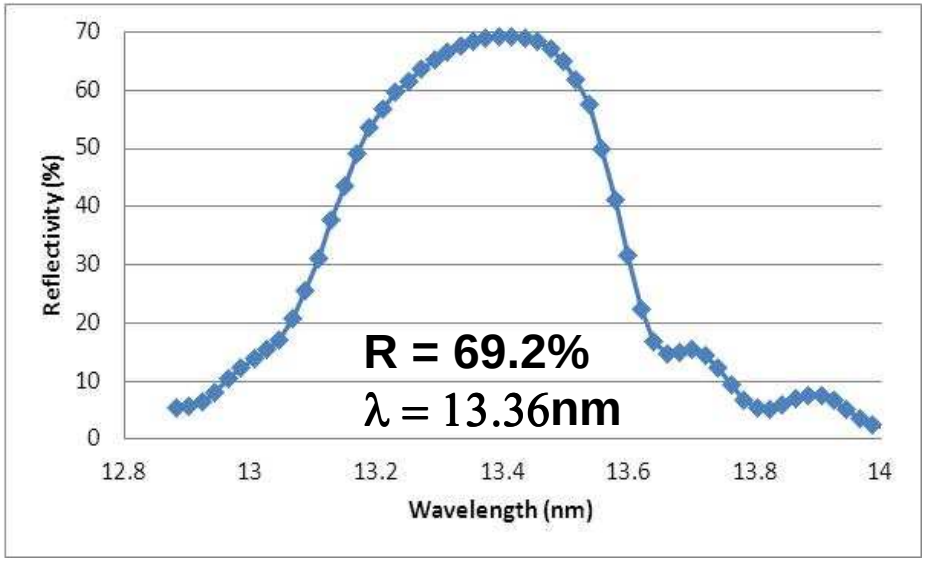
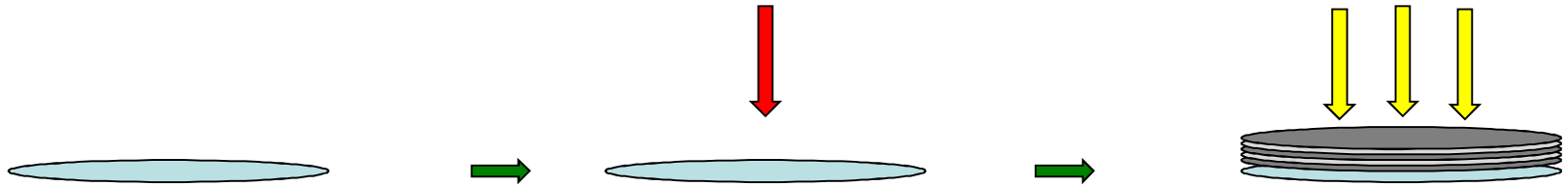
Improvement by substrates polishing



69.2% vs 68.7%



Regular Wafer (AFM RMS=1.5A at 10μm)

Ion Mill treatment (AFM RMS=1A at 10μm)

Mo/Si multilayer

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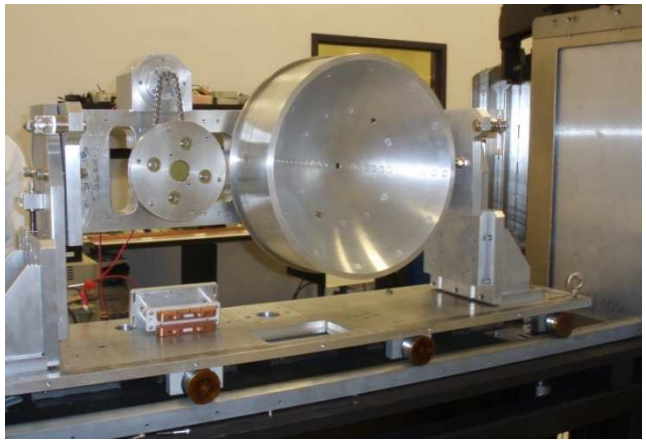
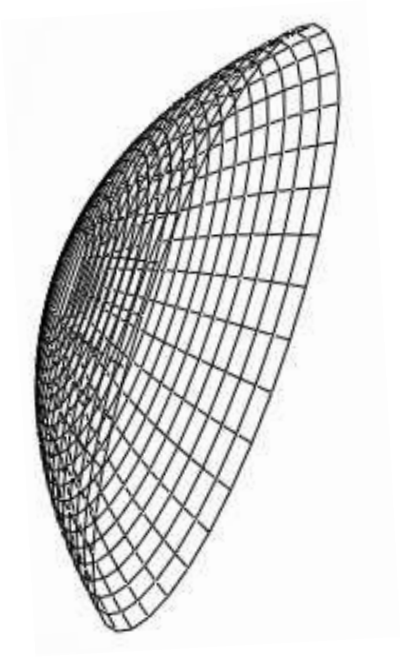
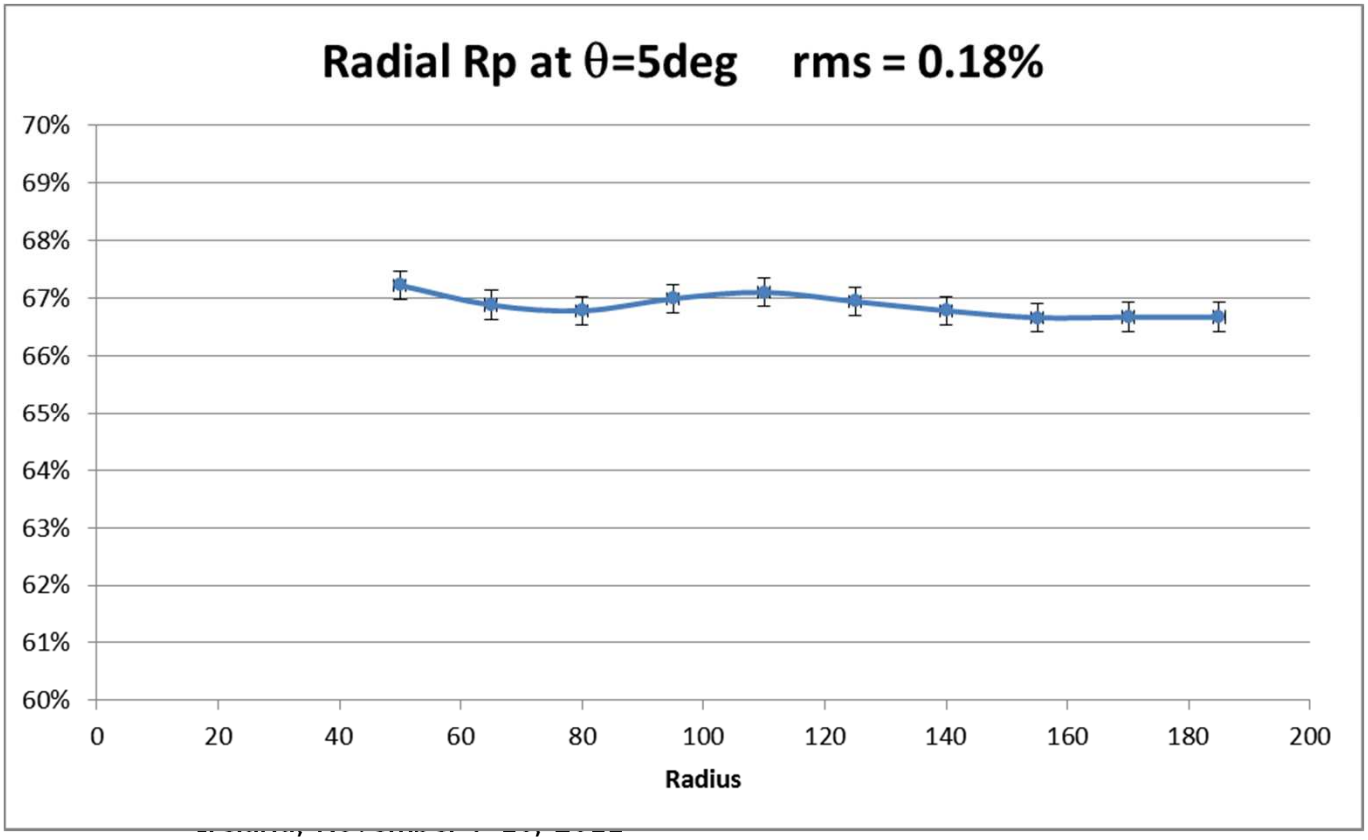
λ=13.5nm: Collector optics

Reflectivity uniformity







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λ=13.5nm: Collector optics

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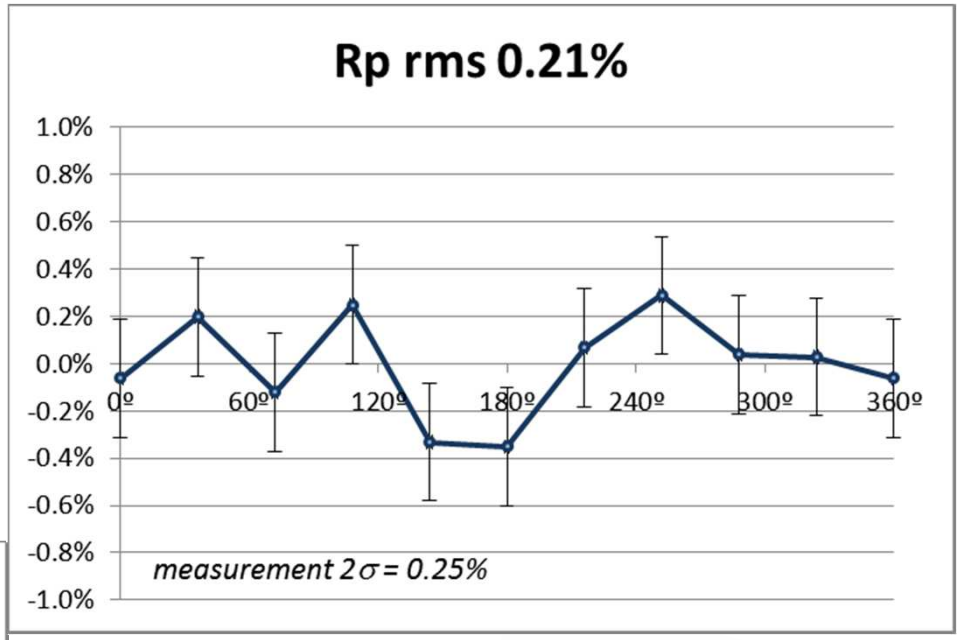
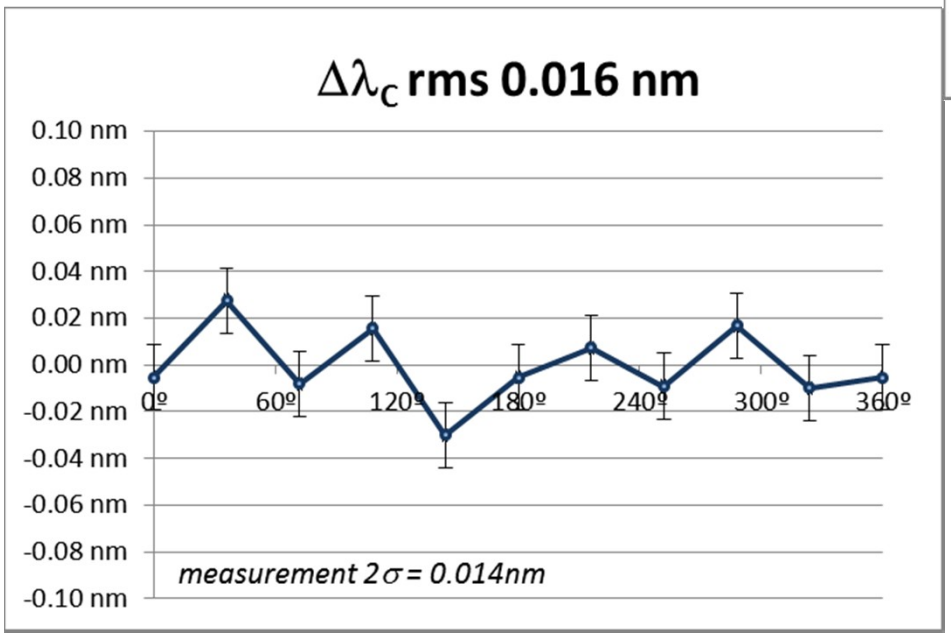
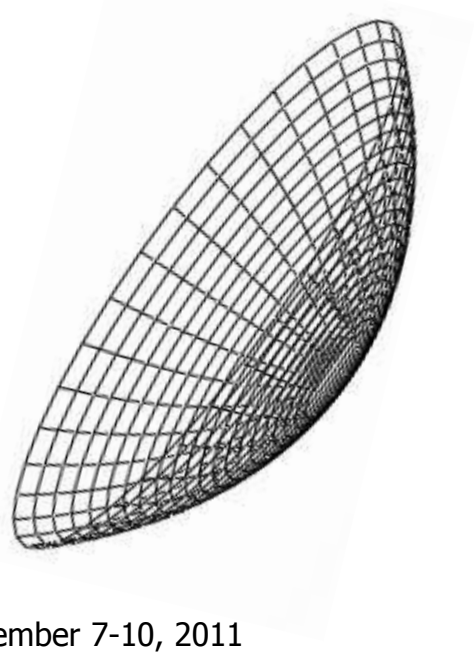
Variation at a Fixed Radius







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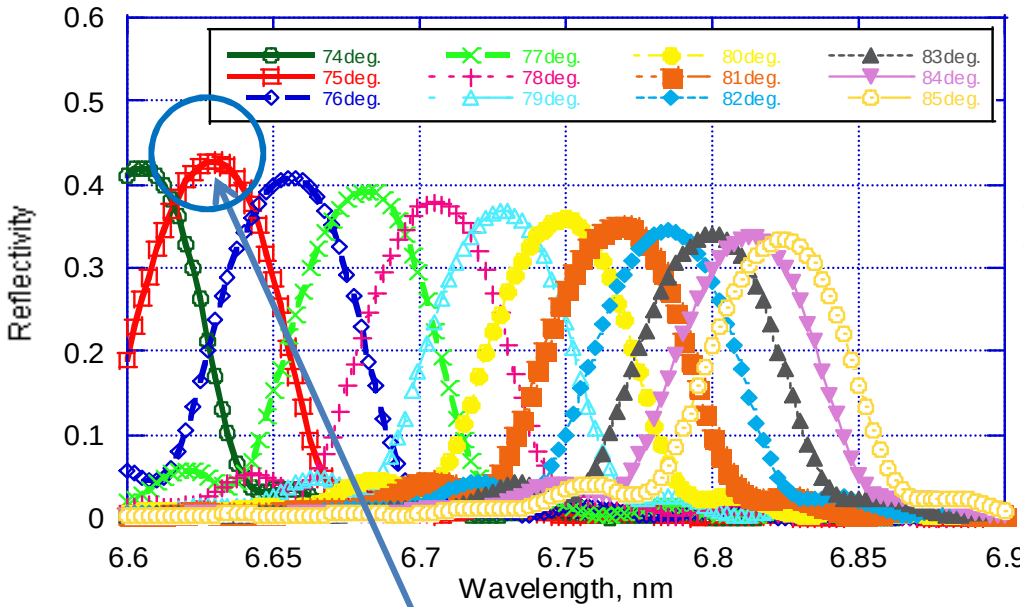
Magnetron deposited and EUV tested multilayers for 6.X nm

No#	Deposition date	XRO#	Pair	N	Measured at λ=0.154nm		Calculated parameters	
					R[1], %	fwhm[1], arcmin	d, nm	gamma
1	Dec.20, 2000	19656-3	La/B_4C	150	16.1	0.8	3.5	0.6
2	Oct.7, 2010	34142-7	La/B_4C	150	17.9	0.96	3.42	0.59
3	Oct.8, 2010	34150-7	La/B_4C	175	19.4	0.97	3.37	0.57
4	Oct.9, 2010	34155-7	La/B_4C	175	18.5	0.98	3.4	0.6
5	Oct.11, 2010	34158-7	La/B_4C	150	20.3	1.02	3.41	0.567
6	Oct.12, 2010	34165-7	La/B_4C	150	20.3	1.11	3.51	0.58
7	Feb.21, 2011	34589-4	La_2O_3/B_4C	150	22.6	0.98	3.45	0.34

Wavelength of maximum reflection

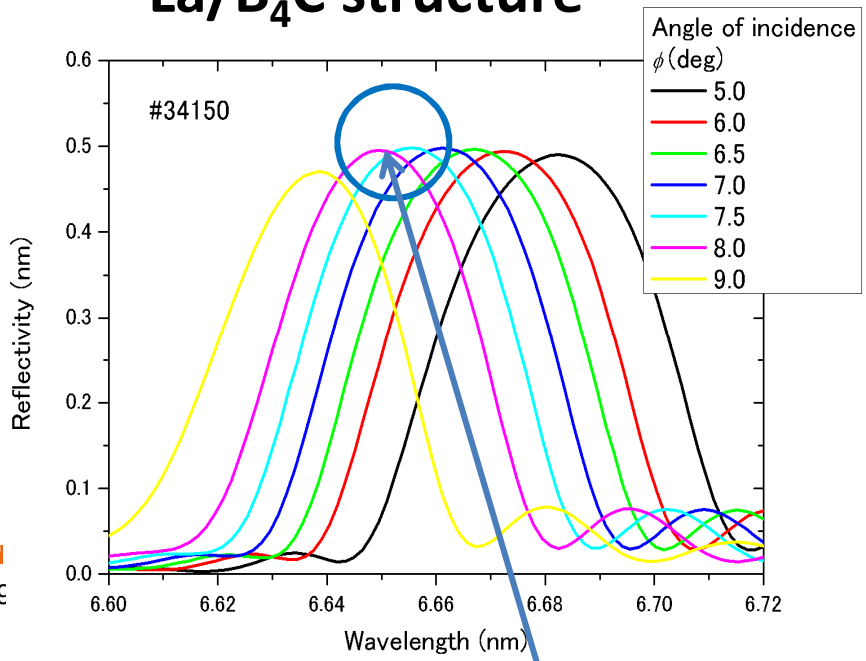
La_2O_3/B_4C structure



Measurements at CXRO, March 2011

R(max)=42.8% at ~6.63nm

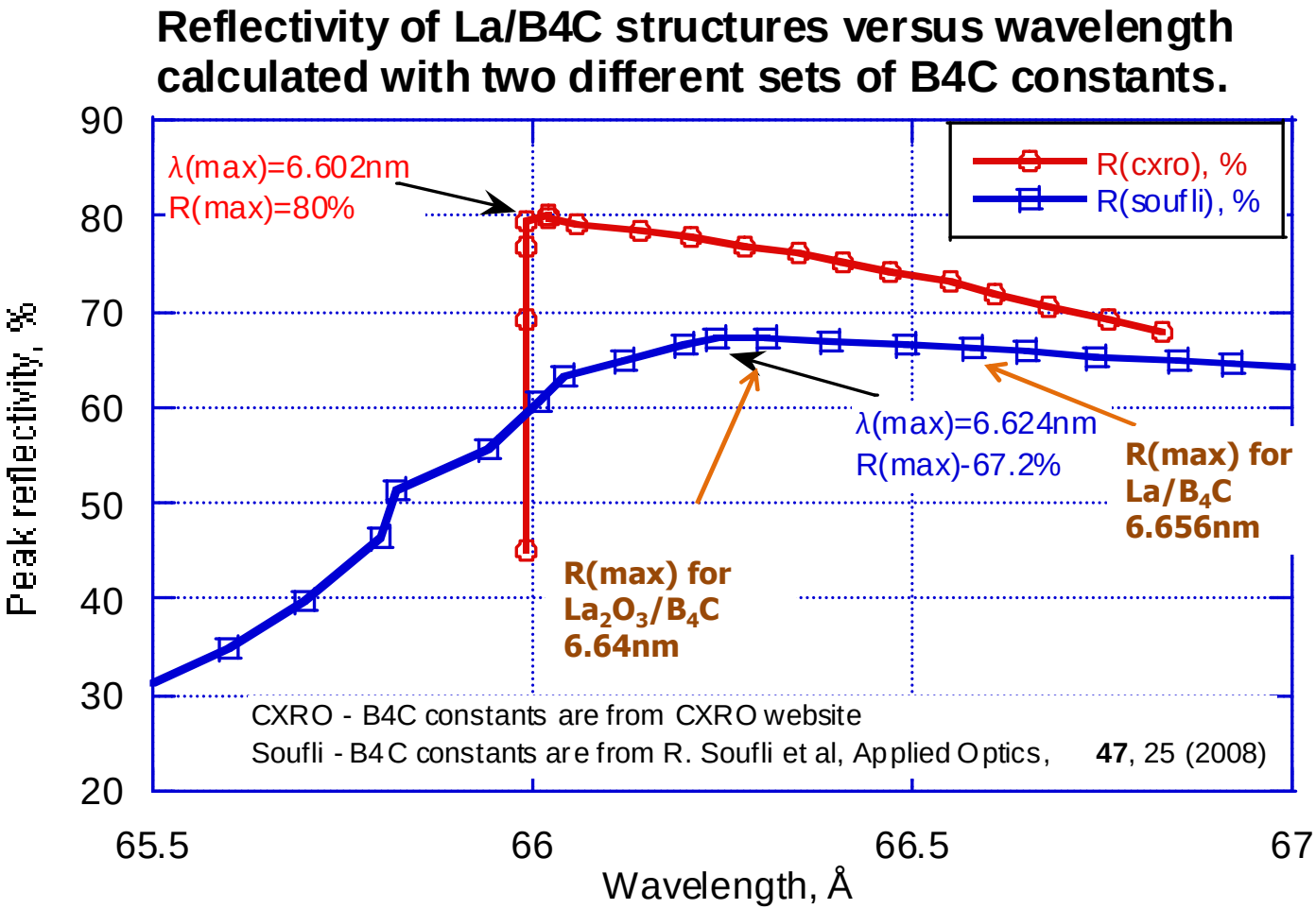
La/B_4C structure



Measurements at New Subaru, May, 2011

R(max)=49.83% at ~6.656nm

Optical constants and maximum reflectivity



Temporal stability of La/B_4C structures

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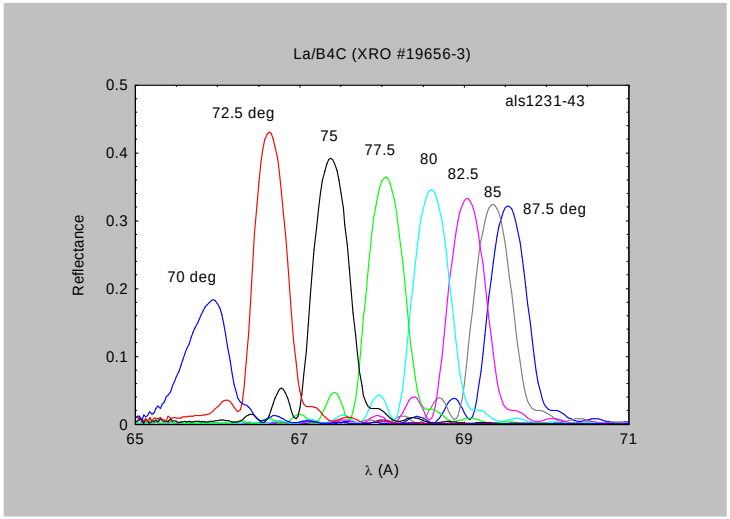
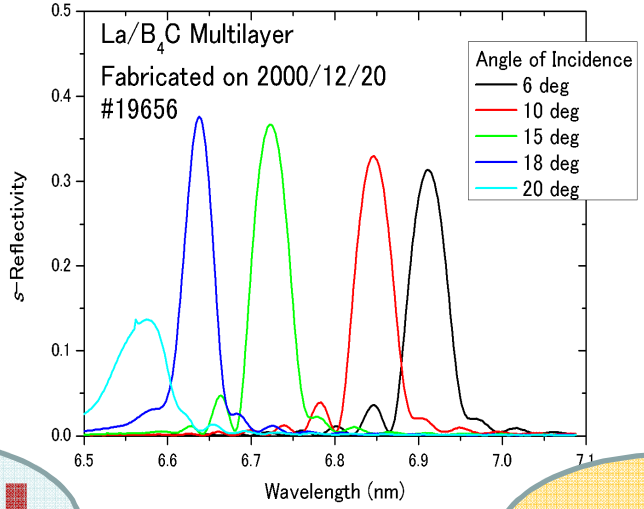
January 2001
Measurements at CXRO



January 2011
Measurements at NewSUBARU



R: 14% ↓

Δλ: 10% ↓

Parameter	CXRO January, 2001	NewSUBARU January 2011
φ, deg.	17.5	18
λ(peak), nm	6.66	6.64
R_p, %	43	37.6
fwhm, nm	0.044	0.04
λ(@ normal), nm	6.98	6.98

Same

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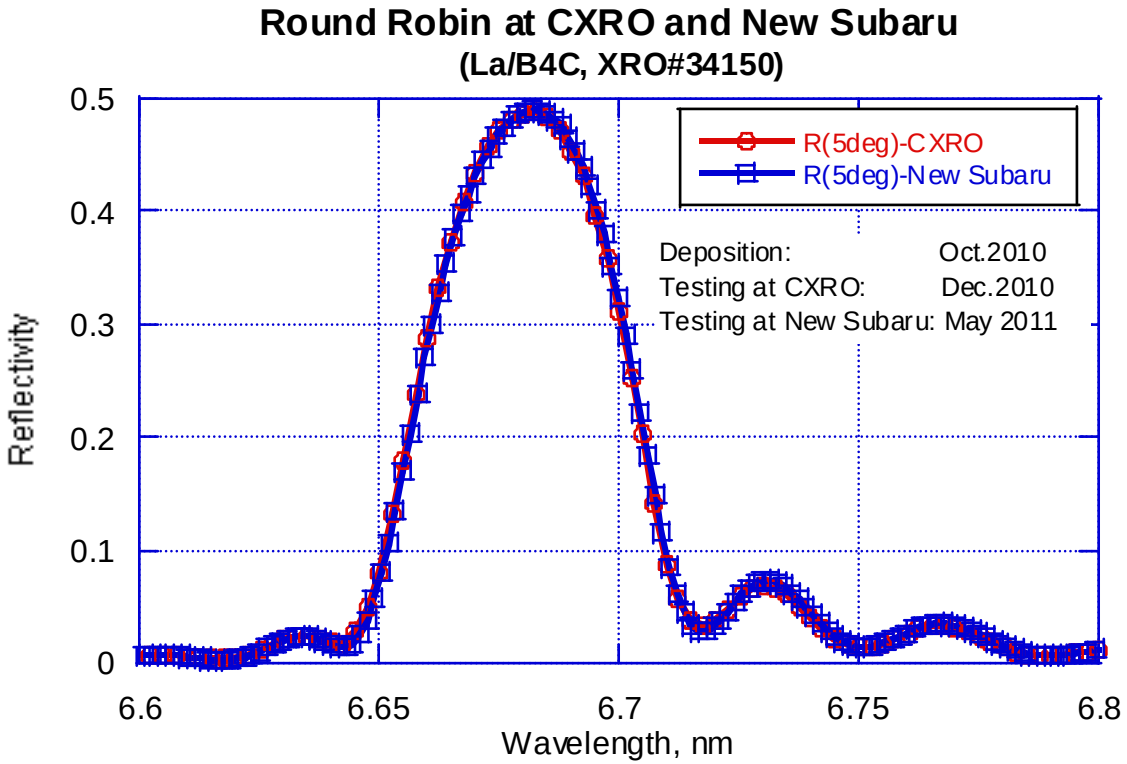
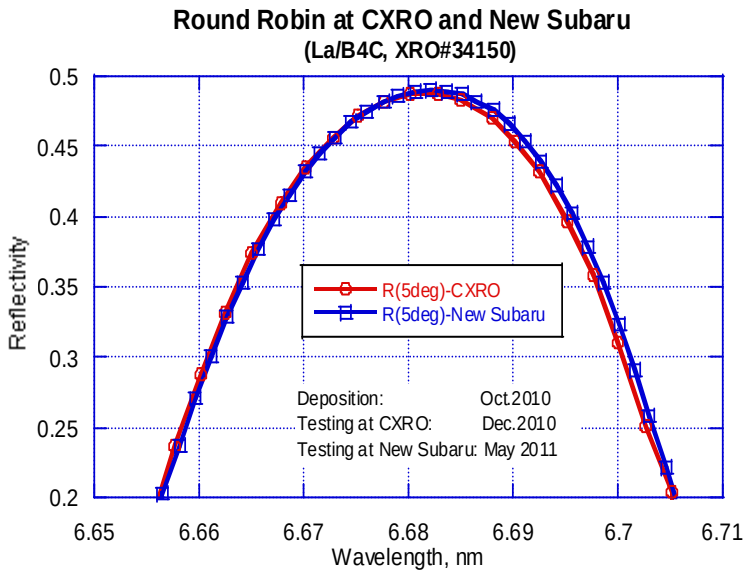
Round robin for La/B_4C. CXRO and New Subaru



Both measurements at 5 degrees off normal



Parameters	CXRO(Dec.2010)	New Subaru(May 2011)
λ(peak), nm	6.683	6.684
R(peak), %	48.7	49.0
FWHM, nm	0.045	0.045

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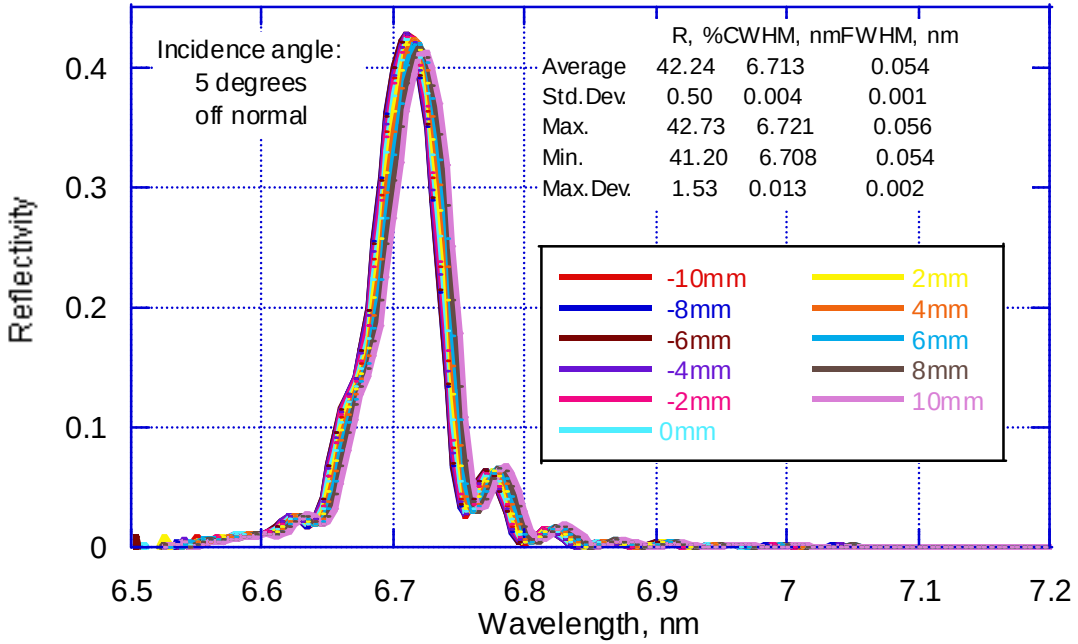
Normal incidence spherical optics for 6.71nm

Measured reflectivity of the spherical mirror
XRO#35414, ROC=500mm. Testing at CXRO: Sept. 28, 2011



Spherical mirror: FS, 1" , r=500mm, XRO#35414, La/B4C, September, 2011.
Measurements were done at CXRO at 5 degrees off normal

Radial position, mm	Reflectivity Peak, %	Centered wavelength (CWHM), nm	Peak wavelength,), nm	FWHM , nm
-10	42.655	6.71	6.71	0.054
-8	42.71	6.708	6.71	0.054
-6	42.728	6.708	6.71	0.054
-4	42.651	6.709	6.71	0.054
-2	42.456	6.71	6.71	0.054
0	42.298	6.711	6.715	0.054
2	42.352	6.713	6.715	0.054
4	42.173	6.714	6.715	0.054
6	41.855	6.716	6.72	0.055
8	41.612	6.718	6.72	0.055
10	41.199	6.721	6.725	0.056

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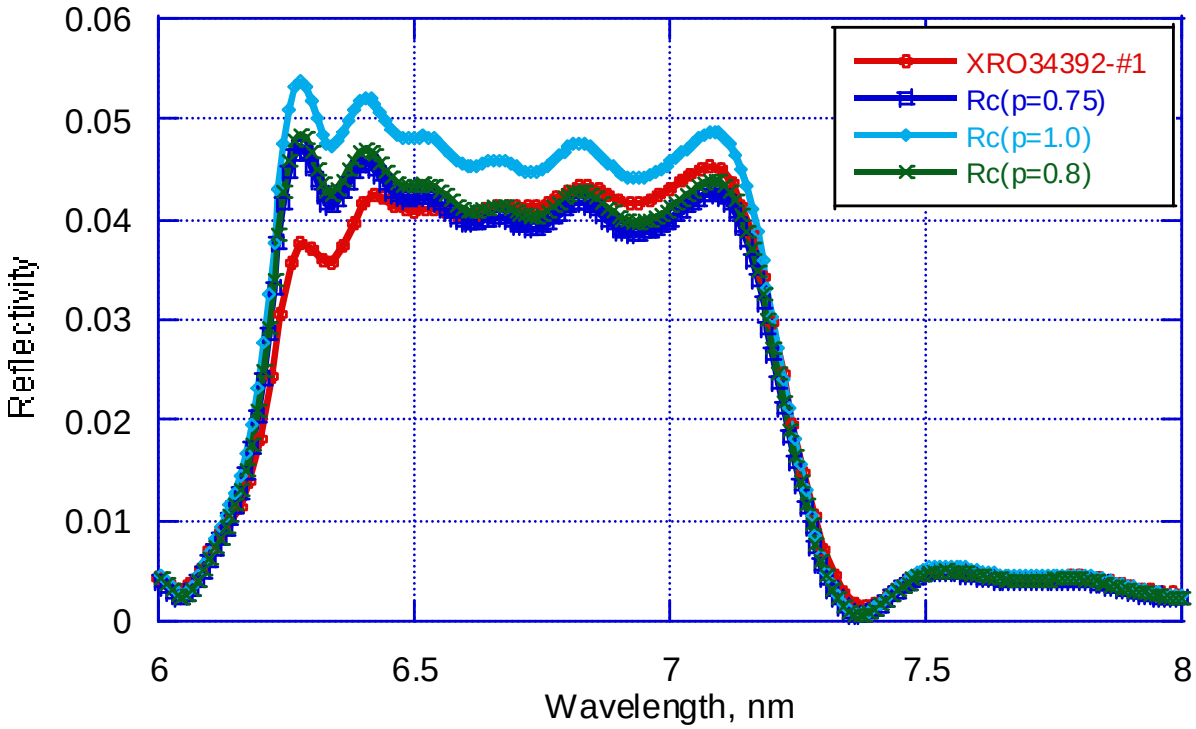
Wide band pass polarizers for 6.7nm

Experimental and calculated for different polarization reflectivity of the depth graded Co/C structure at 45 degrees.
Designed d-spacing distribution and plane waves approximation were used for calculations.



Structure:
Co/C depth graded ML
N=50

Measured reflectivity:
(CXRO, Dec.2010)
$\Delta\lambda$ = 1nm;
$\Delta\lambda/\lambda$ = 15%
R(avg) = 4.1%

ML for ~5nm wavelength

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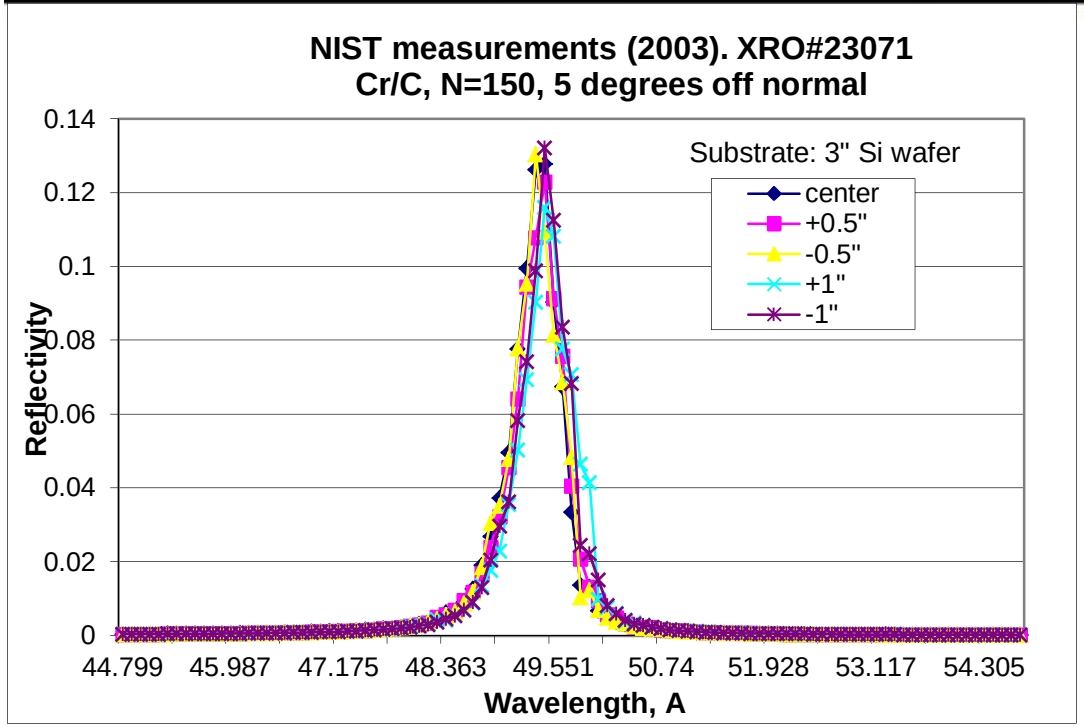


Experimental reflection (2003):

N=150

5° off normal

λ(max) ~ 4.95nm

R(max) ~ 13%,

FWHM ~ 0.048nm

Calculated reflectivity for ideal Cr/C structures:

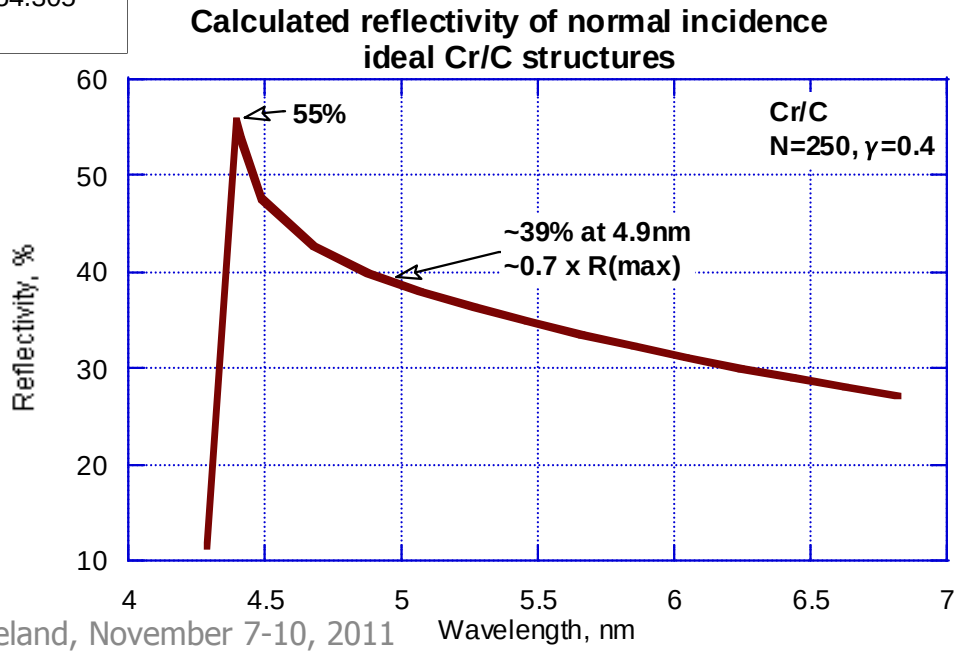
N=250

R(4.95nm) = 39%

FWHM(4.95nm) = 0.028nm

R(N=150)=33%;

FWHM(N=150)=0.036nm



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Multilayers for ~3.1nm

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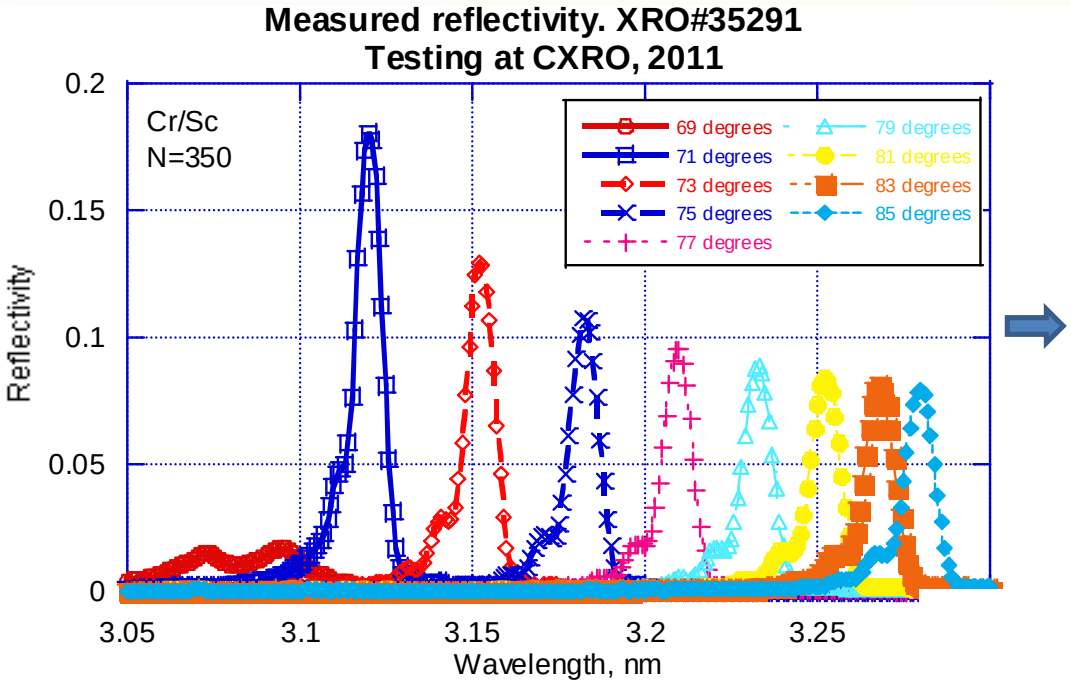


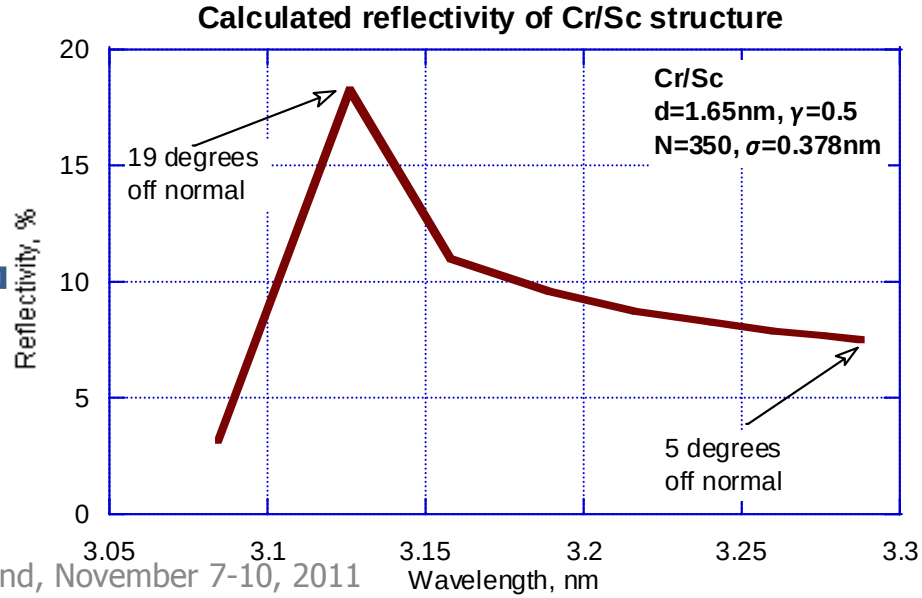
Experimental reflectivity

λ=3.13nm	λ=3.29nm
φ=19°	φ=5°
R(max) ~ 18%	R=8%
FWHM=0.009nm	FWHM=0.01nm

Calculated reflectivity

N=1.65nm, N=350, γ=0.5, σ=0.378nm

λ=3.13nm	λ=3.29nm
φ=19°	φ=5°
R(max) ~ 18.3%	R=7.6%
FWHM=0.009nm	FWHM=0.01nm



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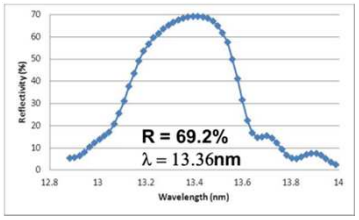
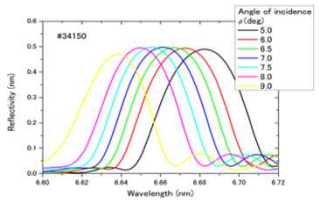
Conclusion



- λ=13.5nm

  Today: R(max)=69.2%

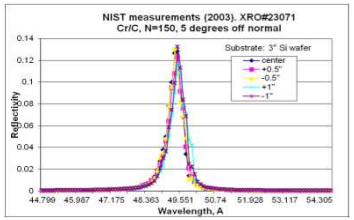
  In ~1year: R(max) ≥ 70% - barrier layers, polishing*



- λ=6.Xnm

  Today: R(max)=49.8%

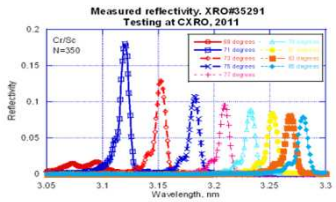
  In ~5 years: R(max) ≥ 60% - barrier layer, new materials (La_xN_{1-x})*



- λ=4.Xnm

  Today: R(max)=13%

  In ~2years: R(max) ≥ 18% - barrier layers*



- λ=3.Xnm

  R(max)=18%

  In ~2years: R ≥ 25% - nitrogen, barrier layers*

* Will depend on dedicated resources

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Acknowledgement

- RIT

  G. Fournier, J. Hummel, C. Coffel, T. Camitan

- CXRO

  E. Gullikson

- LLNL

  R. Soufli

- New Subaru

  T Harada, T. Watanabe, H. Kinoshita

- NIST

  C. Tarrio, S. Grantham, T.B. Lucatorto

Thank you

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